ENERGY EFFICIENCY DESIGN EVALUATION FOR THE TEXAS DEPARTMENT OF CORRECTIONS

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ABSTRACT

A rapid, but comprehensive review of the electrical, mechanical and thermal systems in the maximum security prisons to be built in Amarillo and Gatesville, TX recommended 10 measures for each prison which offered annual savings of $303,000 - $402,000 with an average payback of 1.8 - 2.5 years, depending on the gas rates paid. Subsequent redesign of cell lighting fixtures resulted in reduced first cost of $91,418 and expected annual operating savings in excess of $75,000.

INTRODUCTION

The Texas Governor's Energy Management Center is developing energy standards for state owned buildings. However, state construction programs in progress will result in major new construction before the energy standards can be completed and implemented. In the interim, to ensure that sound energy design practices are followed, the Energy Management Center has initiated a program as part of the State Energy Project at Texas A&M to provide energy review and design assistance for current construction projects of state agencies. The largest projects are within the Texas Department of Corrections. Two 2250 bed prisons have recently been designed and additional 1000 bed units are scheduled for the near future.

The design review project was initiated in November, 1987 and final plans for the two 2250 bed units were due in early January, 1988. The review was scheduled in two phases; a rapid review of the overall energy design features and systems to be completed in December, with provision for a second phase effort on changes which could be incorporated at a later date.

The first phase of the design review was conducted by a team from Texas A&M and Yandell & Hiller, Inc. and is summarized in the first half of this paper. This effort noted that the cell lighting fixtures appeared to offer opportunity for substantially improved energy efficiency through a redesign of the special high security fixture. The fixture redesign is described in the last half of the paper.

ENERGY USE IN THE MICHAELS PROTOTYPE FACILITY

The Michaels Unit was built near Tennessee Colony, Texas in 1986 as a prototype high security prison for the Department of Corrections. Additional units are being built at Amarillo and Gatesville which will differ from the Michaels Unit only where minor improvements are deemed desirable. Consequently, an examination of energy end-uses in the Michaels Unit provides an informative starting point for analysis of possible improvements.

Energy use in the Michaels Unit was carefully examined to determine the major uses and hence the major potential opportunities for lowered operating costs. The breakdowns shown in the figures which follow are based on analysis of limited metered consumption data and analysis of the energy-using equipment in different parts of the facility. Figure 1 shows that over two-thirds of the estimated energy cost of $1,131,641 per year is due to electric use, the remainder being natural gas. The electric use of $760,441 is over half lighting with motors using one-fourth and air conditioning almost 12% as shown in Figure 2. Gas is used primarily for space heating (43%), hot water for showers and washing (25%), in the laundry (17%) and in the kitchen (14%) as shown in Figures 3 and 4. It is likely that a smaller fraction of the gas is used for space heating than is indicated by the fragmentary consumption data used in this analysis.

CONSERVATION MEASURES FOR AMARILLO AND GATESVILLE UNITS

A list of 37 measures was compiled and screened for applicability as shown in Table 1. Of the 37 measures examined, 13 were already included in the plans. Fourteen were recommended for implementation in at least one of the locations, and 10 were rejected because they were inappropriate or the payback exceeded six years. The 10 measures included in Table 1 are briefly described below.

1. Flue Gas Analyzer - Improves boiler efficiency by 2% by optimizing the combustion process.
2. Insulate Walls - 1.5-inches foam are added to uninsulated concrete walls, increasing their R-value from R-2 to R-11.
3. High Efficiency Motors - Specifies minimum motor efficiencies. It is estimated this will add 5% to the average efficiency.
4. Variable Speed Pumping - Slows down pumps which provide cold water for air conditioning when less cooling is needed.
5. Impeller Shaving - Ensures pumps are properly sized by correcting impeller sizing after pump installation.
6. Variable Speed Air Handlers - Slow down fans when less air is needed to heat, cool or ventilate space.
7. Improved Shower Heads - Specifying the most effective and efficient shower heads would cut shower water use by 1/3.
8. Outdoor Lighting - More efficient low pressure sodium lamps replace high pressure sodium lamps.

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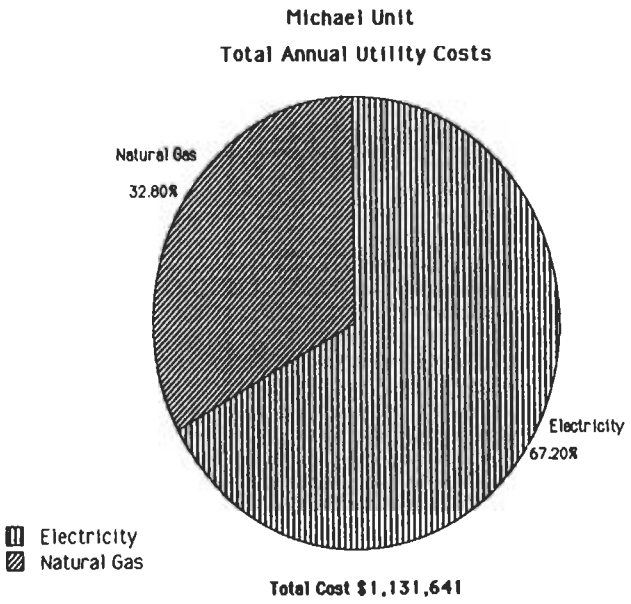

FIGURE 1

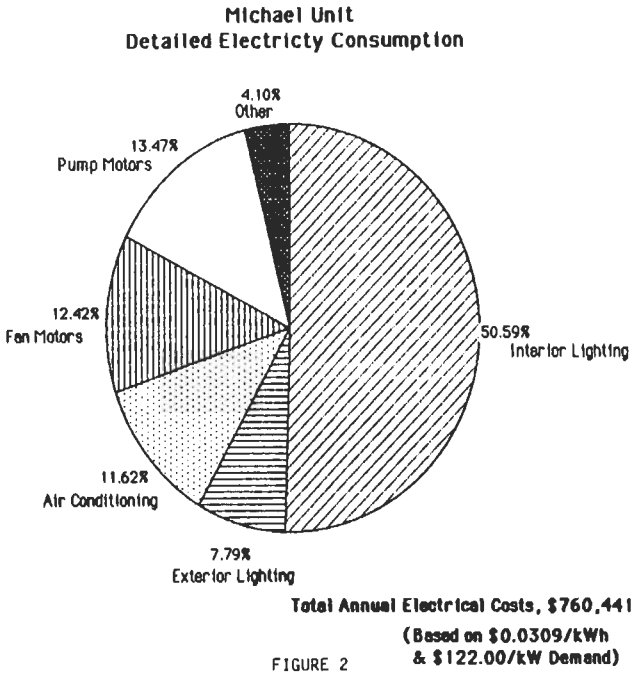

FIGURE 2

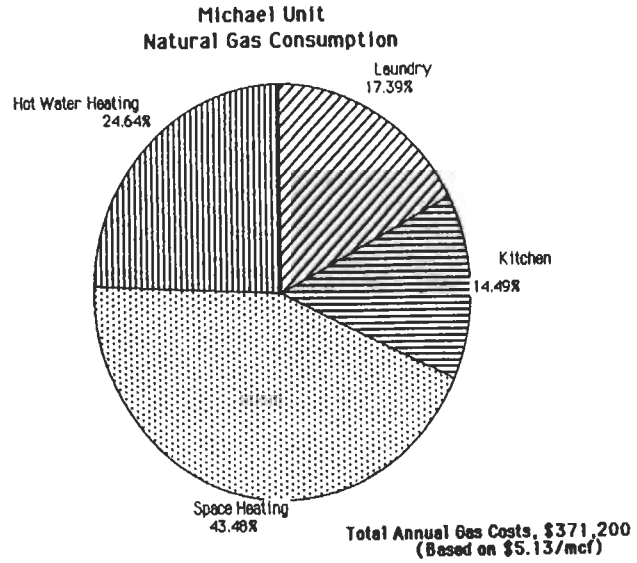

FIGURE 3

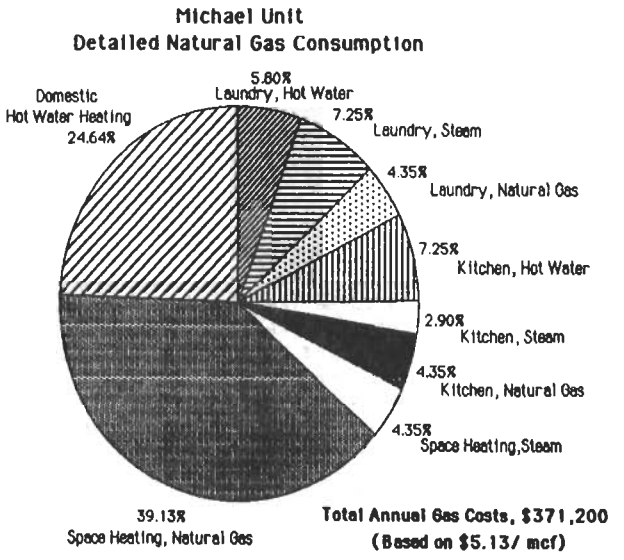

FIGURE 4

9. Lighting Modules - The cell lighting modules to be redesigned so cheaper and lower-wattage flourescent tubes provide enough light.
10. Lighting Controls - Occupancy sensors are used to turn out most lights in large rooms (e.g. dining hall) when they are unoccupied.

The other recommended measures were operating practices which would reduce cost without any initial investment.

OPERATING SAVINGS FROM ENERGY CONSERVATION MEASURES

AMARILLO

The savings expected from the individual energy conservation measures recommended for the Amarillo facility are shown in Table 2. Wall insulation was analyzed and is shown in the package since it was not included in the Michaels prototype unit. It was expected that it would have been specified in the Amarillo unit anyway. The remaining measures would provide annual savings of $107,845 from an investment of $52,188 for an average payback of 0.5 years.

GATESVILLE

Tables 3 and 4 show the savings expected from individual measures for the Gatesville facility under two different gas prices: the current commercial rate of $5.13/MCF and an assumed industrial rate of $3.15/MCF which is close to the rate the facility is expected to pay. The same 10 measures attractive in Amarillo are also attractive in Gatesville with the $5.13 rate. Payback on the wall insulation is slightly shorter, because the lower Btu savings are more than offset by higher gas cost. The overall package offers savings of $229,380 per year with an average payback of 2.2 years.

TABLE 1. CONSERVATION MEASURES CONSIDERED, RECOMMENDED AND REJECTED

Category	# Measures Considered	Already Specified	Recommended	Rejected
Mechanical Equipment	19	7	7	5
AHU & Fans	4	1	2	1
HW, Kitchen & Laundry	6	2	2	2
Lighting	3	1	2	
Insulation	3	2	1	
Alternate Systems	2			2

TABLE 2. ENERGY CONSERVATION MEASURES FOR AMARILLO

	Annual Savings ($)	Initial Cost ($)	Payback (Years)
1. Flue Gas Analyzer	7,886	20,000	2.5
2. Insulate Walls	65,069	445,500	6.3
3. High Efficiency Motors	2,340	4,536	1.9
4. Variable Speed Pumping	2,053	8,543	4.2
5. Impeller Shaving	362	1,600	4.4
6. Variable Speed Air Handlers	6,363	40,752	6.4
7. Improved Shower Heads	24,805	3,020	0.1
8. Outdoor Lighting	2,218	(325)	0.0
9. Improved Lighting Modules	51,864	(27,588)	0.0
10. Lighting Controls	9,954	1,650	0.2
TOTALS	$172,914	$497,688	2.9

When the gas price is reduced to $3.15/MCF, the wall insulation has a payback of 8.3 years, so it has been dropped from the package shown in Table 4. The remaining nine measures offer savings of $129,819 per year with an average payback of 0.4 years.

CELL LIGHTING FIXTURES

During the survey of the prison plans, examination of the cell lighting system revealed that the lighting power was approximately 2.5 watts/ft^2, but observation of the cells showed that lighting levels were relatively low. The lighting for each cell is provided by a four-tube fluorescent fixture mounted behind a stainless steel chase wall; the wash basin, toilet, mirror and electrical outlet are also mounted on the chase wall. The unit is mounted in one corner of each cell, allowing all of the items noted to be serviced from a plumbing chase behind the unit.

The lighting fixture uses four high output 60 watt tubes to achieve a nominal 20 fc light level on the lower bunk. The high output tubes were viewed by maintenance personnel as a problem, since they have a mean lifetime of only 12,000 hours compared with the 20,000 hours of normal tubes and cost about three times as much. They were initially chosen to meet minimum illumination levels specified for the cells while allowing the fixture to be installed entirely outside the cell living area to provide more security.

The lighting fixture consists of an 18 Ga sheet steel troffer, painted with high density, high reflectivity white paint, four 60 watt tubes, 16 Ga stainless steel hardware cloth with a half-inch

TABLE 3. ENERGY CONSERVATION MEASURES FOR GATESVILLE
($5.13/MCF NATURAL GAS)

	Annual Savings ($)	Initial Cost ($)	Payback (Years)
1. Flue Gas Analyzer	18,304	20,000	1.1
2. Insulate Walls	87,097	445,500	5.1
3. High Efficiency Motors	2,905	4,536	1.6
4. Variable Speed Pumping	1,715	8,543	5.0
5. Impeller Shaving	305	1,600	5.3
6. Variable Speed Air Handlers	9,416	40,752	4.3
7. Improved Shower Heads	46,502	3,020	0.1
8. Outdoor Lighting	2,218	(325)	0.0
9. Improved Lighting Modules	51,864	(27,588)	0.0
10. Lighting Controls	9,954	1,650	0.2
TOTALS	$229,380	$497,688	2.2

TABLE 4. ENERGY CONSERVATION MEASURES FOR GATESVILLE
($3.15/MCF NATURAL GAS)

	Annual Savings ($)	Initial Cost ($)	Payback (Years)
1. Flue Gas Analyzer	11,240	20,000	1.8
3. High Efficiency Motors	2,905	4,536	1.6
4. Variable Speed Pumping	1,715	8,543	5.0
5. Impeller Shaving	305	1,600	5.3
6. Variable Speed Air Handlers	9,416	40,752	4.3
7. Improved Shower Heads	40,202	3,020	0.1
8. Outdoor Lighting	2,218	(325)	0.0
9. Improved Lighting Modules	51,864	(27,588)	0.0
10. Lighting Controls	9,954	1,650	0.2
TOTALS	$129,819	$ 52,188	0.4
2. Insulate Walls	53,481	445,500	8.3

square mesh, and a 1/2-inch polycarbonate laminated diffuser with the diffusing prisms mounted inward, facing the hardware cloth and tubes as shown in the sectional view of Figure 5. The diffuser/hardware cloth assembly is welded to the back of the chase wall as shown in the figure.

The polycarbonate was specified to provide a highly secure glazing material, while the hardware cloth backing is provided for additional security.

DESIGN EVALUATION

A full scale mock-up of a two-man cell from the Michaels Unit was built by Department of Corrections personnel and installed at the Energy Systems Laboratory for testing of the lighting fixtures.

The initial design objective was to decrease lighting power by at least 33% while providing the same amount of light as the original design. Hence initial measurements were made with the following four combinations of fluorescent tubes:

1. 4 - 60W 4150 lumen tubes
2. 4 - 40W high efficiency 3700 lumen tubes
3. 4 - 40W standard 3150 lumen tubes
4. 2 - 60W 4150 lumen tubes plus a focusing reflector

These measurements investigated the impact of the diffuser orientation, hardware cloth and aperture size at 15 locations throughout the cell. The position at the head of the lower bunk was found to be most important since it is the reading position which receives the least light. Measurements were made with the measurement surface: (1) horizontal, (2) 60 degrees from horizontal and facing the foot of the bunk, and (3) 60 degrees from horizontal and facing the head of the bunk.

Table 5 shows that 7-27 percent more light reached the measuring surface when the prisms faced the cell than when they faced the fixture as installed in the original design, except when the focusing reflector was used. Then it was advantageous for the prisms to face the fixture.

TABLE 5. Ratio of light level with diffuser prisms facing cell vs prisms facing lighting fixture at bottom bunk for three measurement orientations and four different sets of fluorescent tubes.

Configuration	Measurement Direction		
	(1) Horiz.	(2) 60° to foot	(3) 60° to head
4 - 60	1.18	1.07	1.13
4 - 40 high eff.	1.16	1.23	1.22
4 - 40 stand.	1.26	1.21	1.27
2 - 60 plus refl.	0.89	0.85	0.93

The use of the hardware cloth substantially decreased light levels in every case measured as shown in Table 6. Sixteen to 48 percent more light reached the measurement surfaces when the hardware cloth was removed. However, replacing the hardware cloth with white-painted #3 stainless cane weave with a 2x2-inch mesh size produced a notable improvement over the hardware cloth as shown in Table 7. It also provides greater security.

TABLE 6. Ratio of the light reaching the head of the bunk without the hardware cloth in place to that with hardware cloth in place.

Configuration	Measurement Direction		
	(1) Horiz.	(2) 60° to foot	(3) 60° to head
4 - 60	1.34	1.30	1.43
4 - 40 high eff.	1.48	1.40	1.42
4 - 40 stand.	1.19	1.20	1.16
2 - 60 plus refl.	1.27	1.32	1.33

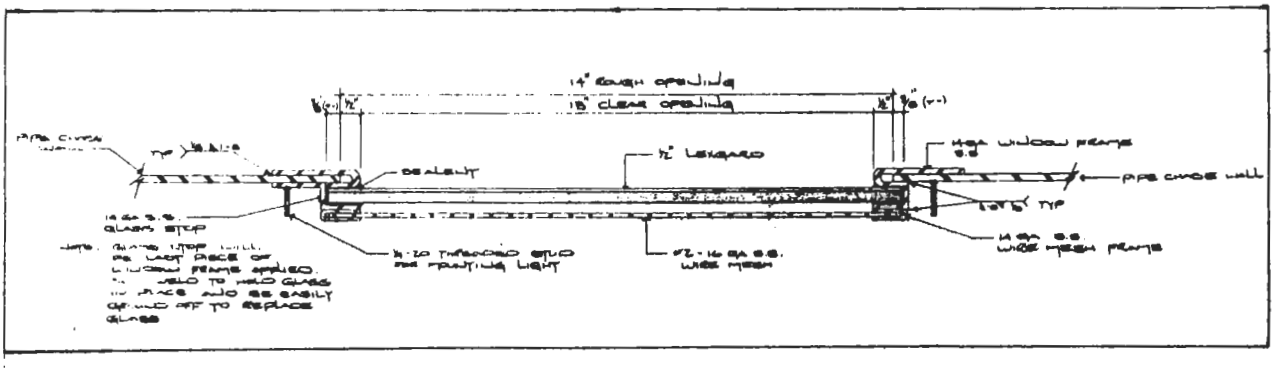

FIGURE 5 Sectional view of chase wall through polycarbonate diffuser.

TABLE 7. Ratio of the light reaching the head of the bunk with white #3 cane wave vs 1/2" hardware cloth.

Configuration	Measurement Surface Orientation	
	(1) Horiz.	(2) 60° to foot
4 x 40 W high eff.	1.30	1.26
4 x 40 W stand.	1.39	1.42

Examination of the light fixture also revealed that the opening of the fixture measured 16x48 inches while the diffuser dimensions were 13x46 inches. Table 8 shows that using a larger diffuser increased the light levels by about 20 percent. These measurements were made with four 60W tubes, prisms facing the cell, and without hardware cloth.

The conclusions were obvious that, in general, the prisms should face the cell, the #3 white-painted stainless cane weave should be used and the diffuser opening should be enlarged.

TABLE 8. Dependence of light reaching the head of the bunk on aperture size.

Aperture	Measurement Surface Orientation		
	(1) Horiz.	(2) 60° to foot	(3) 60° to head
43 x 13 inches	25.6	27.3	24.7
48 x 16 inches	31.8	32.2	30.1
Ratio	1.24	1.18	1.22

TEST PROCEDURE

The initial measurements were made using a variety of positions as noted. A search of IES standards showed that there is no standard measurement position for reading in bed, but a measurement procedure consistent with IES procedures was adopted. The procedure measured the illumination stiking a task plane 12-inches above the mattress, inclined at 45° toward the head of the bunk, with the blanket on the bed and 2-feet of sheet showing.

RESULTS

The remaining measurements incorporated the findings of Tables 5-8 and concentrated on identification of combinations which provide more light than the present design while using less energy. The fluorescent tubes used for the tests of Table 9 were those used earlier, but 34 watt, 2925 lumen tubes were also used and a 3-tube focusing reflector was tried. It was noted that the standard black prison blanket cut light levels substantially, so tests were also conducted with a medium blue blanket and with a light bone-colored blanket.

Table 9 shows the results of these tests. Lighting levels range from 19 percent to 67 percent higher than the base case while total lighting power is 59 percent to 46 percent as great. The cost savings are even more impressive. Table 10 summarizes the economics for installing the modified lighting fixtures in one prison. The fixture costs shown are the materials costs for one fixture, which represents the approximate incremental cost to the state since the fixtures are manufactured at one of the state prisons. The "first cost" is the cost for 1452 fixtures required for one 2250-bed prison while the "annual operating cost" is based on an average electric cost of $0.05/kWh which is typical of the price paid by Texas prisons.

The table shows that three of the five cases shown provide initial cost savings plus annual operating cost savings of $31,269 - $41,868, so the payback is immediate (even after paying for the fixture redesign)! The option selected for implementation uses four 34W tubes, so it will provide initial cost savings of $91,418 in the Gatesville and Amarillo units and annual operating savings of $75,258. This option also offers additional replacement cost savings after 3-4 years of approximately $10,000 and saves the labor of the replacement since the lifetime of the 34W tubes is 20,000 hours instead of the 12,000 hour life of the 60W tubes. The 34W redesigned fixtures provide 29% more light in the darkest reading position and would provide additional light as noted if the blanket color is changed.

CONCLUSIONS

A rapid, but comprehensive examination of the electrical, mechanical and thermal systems in the maximum security prisons to be built in Amarillo and Gatesville has been conducted. It was found that energy efficiency measures have been widely incorporated in the prototype Michaels unit plans examined, but several additional measures were identified which will provide significant reductions in the cost of utilities needed to operate these facilities as shown in Table 11.

Amarillo - Ten measures which will save $172,914 per year with an average payback of 2.9 years were recommended. The current gas and electric rates provide no savings with the cogeneration system examined, so it was not recommended.

Gatesville - With current gas ($5.13/MCF) and electric rates in Gatesville, the 10 measures which were attractive in Amarillo are very attractive, paying back in 2.2 years. Cogeneration was examined and found to have a payback of 6.4 years. The analysis assumed that the cogeneration system is able to purchase natural gas at an industrial rate of $2.00/MCF while the prison purchased gas for its direct-fired uses at a commercial rate of $5.13/MCF. Since it seems probable that gas will be obtained at a lower industrial rate, cogeneration was not recommended.

The same options were also examined under the assumption that an industrial rate of $3.15/MCF would be available to the facility. This increased

the payback of wall insulation to 8.3 years, so it was dropped and the 9 remaining measures pay back in 0.4 years on average. Payback of the cogeneration system was now 13.4 years, so it was not recommended.

The redesign of cell lighting fixtures resulted in fixture cost savings of $91,418 and is expected to provide annual operating cost savings in excess of $75,000.

ACKNOWLEDGEMENTS

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TABLE 9. COMPARISON OF LIGHT LEVEL AND FIXTURE POWER FOR 13 ALTERNATIVES WITH THE BASE CASE

Configuration	Light Level (fc)	Fixture Power (watts) (inc. ballast)	Light Level / Base Case
4x60 Base Case	13.5	290	1.00
4x40 eff., black blanket	22.6		1.67
4x40 stand., bone mattress	22.3	172	1.65
4x40 stand., blue blanket	21.5		1.59
4x40 stand., black blanket	20.1		1.49
2x34+2x40, bone blanket	20.8	160	1.54
4x34+ref, bone blanket	22.1		1.64
4x34 bone blanket	20.0	148	1.48
4x34 black blanket	17.4		1.29
3x40 eff.+ref., black	21.6		1.60
3x40 stand.+ref., bone	21.0		1.56
3x40 stand.+ref., black	19.4	132	1.44
3x40 eff., black	18.2		1.35
3x40 stand., black	16.0		1.19

TABLE 10. ECONOMIC COMPARISON OF BASE CASE AND ALTERNATE LIGHTING FIXTURES

	Cost for 1452 fixtures in 2250 man prison				
	Fixture Cost	First Cost	Annual Operating Cost	First Cost Savings	Operating Cost Savings
Base Case	$67.36	$97807	$76847	---	---
4x40 W High Eff	$44.08	64004	45578	$33803	$31269
4x40 W Standard	$35.88	52098	45578	45709	31269
4x34 W	$35.88	52098	39218	45709	37629
3x40 W High Eff & Ref	$75.14	109103	34979	(11296)	41868
3x40 W Standard plus Ref	$68.99	100173	34979	(2366)	41868

TABLE 11. SUMMARY OF SAVINGS OPTIONS IDENTIFIED

	Annual Savings ($)	Initial Cost ($)	Payback (Years)
Amarillo - 10 Measures	172,914	497,688	2.9
Amarillo - Cogeneration	(49,826)	2,392,000	Never
Gatesville - 10 Measures ($5.13/MCF Gas)	229,380	497,688	2.2
Gatesville - 9 Measures ($3.15/MCF Gas)	129,819	52,188	0.4
Gatesville - Cogeneration ($5.13/MCF Gas)	374,009	2,392,000	6.4
Gatesville - Cogeneration ($3.15/MCF Gas)	178,709	2,392,000	13.4